REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*

2. REPORT DATE
January 14, 2000

3. REPORT TYPE AND DATES COVERED
Final Report

4. TITLE AND SUBTITLE
W-band Polarimetric Monopulse Tracking Receiver

5. FUNDING NUMBERS
DAAH04-96-1-0438

6. AUTHORS
Gabriel M. Rebeiz

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The University of Michigan
EECS Department/College of Engineering
Ann Arbor, MI 48109-2122

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Research Office
P.O.Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
ARO 36346.1-EL

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A planar 94 GHz monopulse receiver has been integrated on a single chip. The receiver is based on four planar antennas followed by four planar subharmonic mixers. The output of the mixers is taken to an IF monopulse processor at 2-4 GHz so as to achieve very deep nulls. The performance of the monopulse receiver has been measured at 94 GHz and resulted in a system NF of around 15 dB, and better than -40 dB nulls in the elevation and difference patterns. Furthermore, the null is maintained at lower than -20 dB over 2 GHz bandwidth. This represents the highest performance monopulse receiver to-date in a planar implementation and is competitive with waveguide systems at W-band frequencies.

Also, we have developed novel distributed wideband MEMS phase shifters suitable for 2-100 GHz applications. The distributed MEMS phase shifters resulted in excellent performance at 40-100 GHz, with an insertion loss of better than 4 dB for a 360 deg. phase shift. To our knowledge, this represents the best phase shifter performance at these frequencies using any technology (diode, HEMT, MEMS).

14. SUBJECT TERMS
Monpopulse receivers, mm-waves, subharmonic mixers, planar antennas, phase shifters, MEMS, 94 GHz radars, phased arrays, polarimetric radars, monopulse processing,

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-1
298-102

DTIC QUALITY INSPECTED 4

20000628172

AD NUMBER	DATE	DTIC ACCESSION NOTICE
1. REPORT IDENTIFYING INFORMATION		REQ
A. ORIGINATING AGENCY U of Michigan		1. Pu on 2. Co
B. REPORT TITLE AND/OR NUMBER W-band Polarimetric ... FR		3. Att m
C. MONITOR REPORT NUMBER ARO 36346.1-EL		4. Us ir
D. PREPARED UNDER CONTRACT NUMBER DAAH04-96-1-0438		5. Do fc
2. DISTRIBUTION STATEMENT A		DTI 1. A 2. R

20000628 172

DTIC Form 50 JUL 96

PREVIOUS EDITIONS ARE OBSOLETE

Final Progress Report
Contract: US Army DAAH04-96-1-0438
Prof. Gabriel M. Rebeiz

(1) Forward:

There is a large need in the 94 GHz frequency range for inexpensive radars capable of monopulse processing for accurate tracking purposes. One way to drastically reduce the cost is to integrate the radar entirely on a single chip. This allows volume production using semiconductor processing techniques which results in ease of fabrication and high reliability. The goal of this work was to demonstrate a planar 94 GHz monopulse processor capable of very high accuracy tracking using planar receiver techniques.

Also, a novel area of technology is investigated in this proposal. It is the use of MEMS (Micro-electromechanical systems) to develop very low insertion loss components and phase shifters at mm-wave frequencies. We have developed a novel distributed phase shifter capabale of 2-100 GHz operation and have used it in obtaining excellent phase shift and low insertion loss at 40-100 GHz.

(2) Table of Contents:

Not Applicable

(3) List of Appendices, Illustrations and Tables:

Not Applicable

(4) Statement of the Problem Studied:

(5) Summary of the Most Important Results:

1- Developed planar slot-ring antennas for 94 GHz applications with excellent patterns.

2- Developed planar subharmonic mixers for 94 GHz operation with better than 7 dB conversion loss.

3- Developed a planar monopulse IF processor at 2-4 GHz with better than 40 dB nulls (narrowband) and 30 dB nulls (wideband)

4- Developed a planar 94 GHz monopulse receiver on a single chip with excellent monopulse nulls (better than 30 dB over a 2 GHz bandwidth) in the elevation and azimuth planes. The NF of the receiver was better than 15 dB at 94 GHz.

5- Developed novel MEMS technology for switches and phase shifters.

6- Used the MEMS technology for the construction of wideband phase shifters for 2-100 GHz applications, and obtained 4-5 dB loss for a 360 deg. phase shift for 40-100 GHz applications.

(6) List of all Publications and Technical Reports:

Journal Papers:

1- S. Raman and G.M. Rebeiz, "Single- and dual-polarized millimeter-wave slot-ring antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-44, pp. 1438-1444, Nov.1996.

2- S. Barker and G.M. Rebeiz, "IF-based polarimetric receivers," *IEEE Microwave Guided-Wave Letters*, vol. MGWL-7, pp. 81-83, March 1997.

3- S. Raman and G.M. Rebeiz, "A high-performance uniplanar W-band subharmonic mixer," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-45, pp. 955-962, June 1997.

4- G.P. Gauthier, S. Raman and G.M. Rebeiz, "A 90-100 GHz double folded-slot antenna," *IEEE Trans. Antennas Prop.*, March 1998. To appear October 1998. 1998.

5- N.S. Barker and G.M. Rebeiz, "Distributed MEMS true-time delay phase shifters and wideband switches," *IEEE Trans. Microwave Theory Tech.*, Vol. 46, pp. 1881-1890, Nov. 1998. **(IEEE 2000 Microwave Prize)**

6- S. Raman, S. Barker and G.M. Rebeiz, "A W-band dielectric-lens-based integrated monopulse radar receiver," *IEEE Trans. Microwave Theory Tech.*, Vol. 46, pp. 2283-2288, Dec. 1998.

7- N.S. Barker and G.M. Rebeiz, "Optimization of distributed MEMS transmission line phase shifters," Submitted for publication in the *IEEE Trans. Microwave Theory Tech*, Dec. 1999.

8- N.S. Barker and G.M. Rebeiz, "Distributed Ka-band MEMS transmission line BPSK modulator," Submitted for publication in the *IEEE Microwave and Guided Wave Letters*, Dec. 1999.

Conference Papers:

1- S. Raman and G.M. Rebeiz, "Integrated millimeter-wave polarimetric radar receivers," *IEEE National Radar Conference*, Ann Arbor, MI, pp. 232-237, May 1996.

2- S. Raman and G.M. Rebeiz, "A 94 GHz uniplanar subharmonic mixer," *IEEE MTT-S Int. Microwave Symp.*, pp. 385-388, June 1996. **(Best Student Paper Award.)**

3- S. Barker and G.M. Rebeiz, "Planar front-ends with polarization agile IF systems," *IE E AP-S Symp.*, Epp. 1532-1535, July 1996.

4- G.M. Rebeiz, S. Raman, T. Ellis, G. Gauthier and S. Barker, "High-performance mm-wave sensors using uniplanar and micromachined technologies," **Invited Paper**, *WRI Int. Symp.*, NY, Sept. 1996.

5- G.M. Rebeiz, S. Raman, G.P. Gauthier and T.J. Ellis, "Advances in millimeter-wave antenna and sensor front-end technologies," **Distinguished (Invited) Speaker,** *Int. Symp. Antennas and Propagation (ISAP)*, Chiba, Japan, pp. 1221-1244, Sept. 1996.

6- N.S. Barker and G.M. Rebeiz, "An octave bandwidth monopulse process," *IEEE MTT-S Int. Microwave Symp.*, Denver, CO, pp. 405-408, June 1997. **(Student Paper Award.)**

7- S. Raman and G.M. Rebeiz, "Single and dual-polarized slot-ring subharmonic receivers," *IEEE MTT-S Int. Microwave Symp.*, Denver, CO, pp. 565-568, June 1997.

8- S. Raman, G.P. Gauthier and G.M. Rebeiz, "W-band on-wafer measurements of uniplanar slot-type antennas," *IEEE AP-S,* Montreal, Canada, pp. 554-557, June 1997.

9- S. Raman, N.S. Barker, and G.M. Rebeiz, "A W-band dielectric-lens-based integrated monopulse radar receiver," *1998 IEEE MTT-S Int. Microwave Symp.,* Baltimore, MD, pp. 517-520, June 1998.

10- N.S. Barker and G.M. Rebeiz, "Distributed MEMS true-time delay phase shifters," *22nd Annual Antenna Applications Symp.*, IL, Sept. 1998.

11- N.S. Barker and G.M. Rebeiz, "Novel wideband distributed MEMS phase shifters and high isolation switches," *European Microwave Conference,* pp. 730-734 (vol. 2), Amsterdam, Oct. 1998.

12- N.S. Barker and G.M. Rebeiz, "Optimization of distributed MEMS phase shifters," *1999 IEEE-MTT Int. Microwave Symp.,* pp. 299-302, Los Angeles, CA, June 1999. **Best Student Paper Award.**

(7) List of all Participating Scientific Personnel Showing an Advanced Degrees Earned:

Sanjay Raman, 1996-1998.
Earned his Ph.D. in Electrical Engineering and Computer Science in January1998.
Sanjay is an Assistant Professor of Electrical Engineering at Virginia Tech., VA.

Scott Barker, 1996-1999
Earned his Ph.D. in Electrical Engineering and Computer Science in August 1999.
Scott is Member of Technical Staff at the Naval Research Labs, VA.

(8) Report of Inventions and Awards:

<u>IEEE 2000 Microwave Prize Award</u>

N.S. Barker and G.M. Rebeiz, "Distributed MEMS true-time delay phase shifters and wideband switches," *IEEE Trans. Microwave Theory Tech.*, Vol. 46, pp. 1881-1890, Nov. 1998.

First Place, Student Paper Award, 1996 IEEE MTT Symposium

S. Raman and G.M. Rebeiz, "A 94 GHz uniplanar subharmonic mixer," *IEEE MTT-S Int. Microwave Symp.*, pp. 385-388, June 1996.

First Place, Student Paper Award, 1999 IEEE MTT Symposium

N.S. Barker and G.M. Rebeiz, "Optimization of distributed MEMS phase shifters," *1999 IEEE-MTT Int. Microwave Symp.*, pp. 299-302, Los Angeles, CA, June 1999.

(9) Bibliogrpahy

See above